The Drexel Institute

Monographs

THE ROMANCE OF ENGINEERING

A LECTURE

DELIVERED AT THE DREXEL INSTITUTE
FEBRUARY 16, 1916

BY

C. J. TILDEN
Professor of Civil Engineering
The Johns Hopkins University

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The remarkable and rapid development of modern engineering has brought many of its more dramatic phases into public light. Artists, both with pen and pencil, have made use of the opportunities offered, and stories have been written and pictures painted in which the central feature of the composition is some engineering creation, either of fact or of imagination. Many of Kipling's stories, as for example "The Bridge Builders" and ".007," are striking bits of romance, with singular truthfulness of detail, in the field of modern engineering, and Pennell's sketches of the Panama Canal throw a new and most interesting light on that great work.

The subject of this afternoon's talk is not, however, modern engineering, except in so far as it is a development, just as every human activity must be, out of the inspiration and the efforts of men of past ages, but rather a glimpse at two or three periods of history of which there is record of engineering endeavor. An interesting factor, at once suggested by these considerations, is that of time, and an effort is made to show this time factor in its relation to these periods of engineering activity, with especial reference to one phase of this activity in the Romance period. Now, an engineer prefers to express his ideas, whenever possible, by means of a drawing or diagram, and so an attempt has been made in the accompanying chart* to show graphically this time relation of historical events.

In this "graphical exhibit" of the time-function time is laid off horizontally to scale for a period of over twenty-three hundred years—from the fourth century B.C. to the pres-

* The basic idea of this chart was obtained from Clemens Herschel's interesting and scholarly edition of Frontinus' "Two Books on the Water Supply of the City of Rome." In order to show certain time-relations of the Roman period Mr. Herschel developed this scheme of making a scale drawing, so to speak, of the time-function. The chart shown herewith is simply an adaptation and extension of the same idea to a longer period.

ent—the main divisions being marked as centuries while the smaller sub-divisions show intervals of a decade. The vertical sub-divisions, covering ninety years to the same scale as the horizontal, represent similarly the span of human life, so that the lifetime of an individual is shown as a straight inclined line, at forty-five degrees to horizontal (or vertical) whose ordinate, or height above the base-line, at any point shows the age of the individual while the corresponding abscissa (horizontal distance) gives century and year of the Christian era. Thus Archimedes whose life spanned the greater part of the third century before Christ, is shown graphically, so to speak, by the inclined line running from 287 B.C. to 212 B.C. and reaching a height (age) of 75 years. In general, the names have been picked out rather at random, many of them being entered on the drawing merely to perform the function of convenient and easily recognized mile-posts, while a few are those of men who have had an important part, each in his day, in the development of engineering.

It is worth while to note the two lines at the right of the lowest line of the diagram representing respectively the first and the twenty-eighth presidents of the United States. The fact that the time-function of our national life is included between these lines gives, perhaps, a better idea of the scale of the diagram than anything else.

In some cases it has not been possible to find the dates of birth and death, and the inclined lines must then be omitted, the name alone appearing as near to its proper place, chronologically, as it is possible to put it. Of Hippodamus, for example, a Greek architect of Miletus, little is known except that he lived some four or five hundred years before Christ, and planned and built cities. Dinocrates, "a great and original Greek architect" of a little later period, was a contemporary of Alexander the Great, for whom he also built cities, but the date of his birth and death are not known. There is similar lack of exact knowledge concerning Vitruvius, but he appears to have lived in the time of Augustus and wrote a treatise on Architecture, (which at

that time included also all branches of Engineering, both military and civil), which was destined later to exert a strong influence on the character and development of the art of building.

Certain other time phases of this treatise of Vitruvius are further shown by some of the entries on the chart. The *De Architectura Libri Decem** was written, probably, just about the beginning of our era, but the oldest known manuscript dates from the tenth century or thereabouts. For another five hundred years this manuscript lay practically unknown until its discovery at the Monastery of St. Gall. It is seen that this discovery took place just as the interesting period known as the Renaissance was beginning, and it is easy to conceive with what interest such a voice from the past would be received. Vitruvius is didactic and tedious in places, but he presents his views systematically and with emphasis, and his treatise was pretty generally accepted by the architects of the Renaissance as an unquestioned authority.

To the modern engineer there is much of interest in the writings of Vitruvius. He divides the field of Architecture into three main divisions as follows:

1. The Art of Building.
   a. The construction of fortified towns and of works for general use in public places—
      I. For defensive purposes—the planning of walls, towers and gates, permanent devices for resistance against hostile attacks.
      II. For religious purposes—the erection of fanes and temples to the immortal gods.
      III. For utilitarian purposes—the provision of meeting places for public use, such as harbors, markets, colonnades, baths, theatres, promenades, and all similar arrangements.
   b. The putting up of structures for private individuals.

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*The latest English translation of the "De Architectura" is by Professors Morgan and Howard of Harvard University, with drawings prepared under the direction of Professor Warren. It was published in 1914.

2. The Making of Time-pieces. (Sundials, water clocks, etc.)
3. The Construction of Machinery—
   a. Civil—water wheels, screw pumps, hodometers, etc.
   b. Military—balistæ, catapults, rams, siege machines, etc.

In the light of modern developments of engineering this seems a fairly comprehensive group of subjects. Some of the specific chapters in Vitruvius are, however, much more clearly related to present day ideas. The details which he gives of construction in wood and masonry, and especially in brick, are full and complete, and many times quite in accord with modern practice. His description of the tests that should be applied to sand to determine its fitness for use in mortar might almost be taken directly from masonry specifications of to-day, and the use of the inverted siphon, rediscovered and invented again by hydraulic engineers of not very many years ago, seems to have been pretty well understood by the Roman builders of that day.

One paragraph in Vitruvius is worth quoting in full in view of the increased importance within the last few years of the valuation of engineering structures, and the widespread discussion of the principles underlying valuation work. The following is from Chapter VIII of Book II:

"No walls made of rubble and finished with delicate beauty—no such walls can escape ruin as time goes on. Hence, when arbitrators are chosen to set a valuation on party walls, they do not value them at what they cost to build, but look up the written contract in each case and then, after deducting from the cost one-eightieth for each year that the wall has been standing, decide that the remainder is the sum to be paid. They thus in effect pronounce that such walls cannot last more than eighty years.

"In the case of brick walls, however, no deduction is made provided they are still standing plumb, but they are always valued at what they cost to build."

Here is an interesting and simple "straight-line" formula for depreciation, as well as a highly common-sense view to

take of brick walls that still "stand plumb," which should receive the careful consideration of valuation engineers.

Another record of engineering work of the time of Imperial Rome is that of Sextus Julius Frontinus, for many years Water Commissioner of the city, an important office which he seems to have filled with honor and a fine public spirit. Frontinus' work consists of two books, or short essays (for the total in English translation amounts to less than twenty thousand words), describing the various aqueducts which brought water into the city. There is more genuine thought to this work than is shown in Vitruvius; apparently Frontinus took himself less seriously and his work more seriously than the earlier engineer.

In the introduction he speaks of the high office which had just been conferred upon him by the emperor, and expresses his gratification at the honor and his realization of its importance to the health and welfare of the city. He then reviews briefly the history of the Roman water supply from the foundation of the city and describes the various aqueducts, and the Consuls and others who were responsible for building them. He is immensely proud of these great works and after several pages of description he asks the question, "Will anyone compare the idle pyramids or those other useless though much renowned works of the Greeks with these aqueducts?" He then tells how in accepting the office of Water Commissioner from the emperor he felt it his duty to examine carefully all the channels, in order to determine what amounts of water they should bring into the city and which ones were failing in their duty.

Frontinus evidently spent much time and thought on this question of measuring the flow of water and he describes in detail the unit of measure which he called the *quinaria*. The quinaria, however, was merely a spout with a given cross-sectional area—a circular orifice with a diameter a little less than one inch in modern measure. Frontinus gives the credit for this unit to Vitruvius, and spends a good deal of time describing the pipes and how they were used. But he fails to recognize the fact that a one-inch diameter

pipe will discharge varying quantities of water depending upon the depth of the water above the opening. He tried hard to check up the quantities of water flowing to the city through the various aqueducts, and calls attention to two evils with regard to the distribution of water, first, the dishonesty of those who surreptitiously tapped either the aqueducts or distributing pipes, and secondly, the special favors which were often granted to powerful or influential individuals. His organization for the repair and the maintenance of the aqueducts is also described, and he discusses the various maintenance difficulties such as the formation of incrustations from the very hard water from most of these springs, the destruction of the concrete lining resulting in leaks, etc., and also states the rule that only one aqueduct should be repaired at a time in order that the continuity of the supply to the city should not be broken. It was a rule of the Senate that spaces should be kept clear and unoccupied for fifteen feet on each side of the springs, arches and walls of the aqueducts in order to facilitate keeping them clean and in proper repair.

In fact, the impression one gets from reading Frontinus' highly entertaining little book is that the water supply of Rome was in general quite as well organized as that of a modern city, and that honest city officials had much the same difficulties to contend with, both from conscienceless individuals and from those who abused political power and influence, as are found to-day. Still more interesting, perhaps, is the picture that one gets of the author of the book, Frontinus himself. He was evidently a man of influence and power, trusted by the emperor, and with a long record of distinguished service to the state. He wrote several other works in addition to the "De Aquis," one on stratagems of war, a treatise on surveying, one on boundaries, roads, etc., and a work on Roman colonies. He had earned an excellent reputation as a soldier and the post of water commissioner was apparently the culmination of his career.

Until 1899 there was no English translation of Frontinus' "De Aquis." At that time Mr. Clemens Herschel, the well-

known hydraulic engineer, in New York, published his delightful book in which he gives not only a translation, but also a photographic reproduction of the oldest manuscript, the "Montecassino Codex," as he calls it, of Frontinus' work. This manuscript is a precious document of 23 pages of parchment written in the cramped, uncial writing of the middle ages, and kept in the library of the monastery of Montecassino in Italy. In his detailed comment on the essay Mr. Herschel makes one point which is particularly interesting as coming from a scientific scholar who has given so much thought to the whole subject. This is in reference to the popular idea that the Roman engineers believed that the conduits which brought the water into the city should be kept level, or with only a slight fall, to allow the water to flow from the source of supply to the point of distribution within the city. Mr. Herschel contends with some emphasis that people who were capable of building and maintaining such an elaborate and beautiful system of water supply must know the fundamental principle of the syphon. "Let us stamp out if we can," he says, "the shallow idea that those men did not know that water would rise as high in the pipe as the source from which it came." He cites Vitruvius who, as mentioned above, tells how to build inverted syphons, saying that it could be done with lead pipe or drawn pipe, and also quotes Pliny the Elder, to the effect that "water climbs to the height of its own origin." Then he goes on to say that it is not difficult to find the reason why the Romans seldom used the principle of the inverted syphon. "They did simply what every engineer does at the present day. . . . At every point of operation a good engineer will use to the best advantage possible, the materials and facilities for his work found at hand for the time being; and this is what the Romans did. Not having cast iron pipes, they builded as could best be done without them, and were we deprived of cast iron, wrought iron, and steel pipes, we should to-day be obliged to build water works pretty much as they built them."

Mr. Herschel comments amusingly on the utter impossibil-

ity of following Frontinus' arithmetical computations, in the chapter in which the honest old commissioner tries to figure out water quantities, etc. It certainly appears impossible to reach his conclusions by any of the accepted rules of arithmetic. This is not surprising, however, when it is remembered that the earliest record that we have of what Frontinus wrote was penned fully 1100 years after he wrote it. The Montecassino manuscript dates from about the 12th century, and although there is indication that it was copied from a manuscript of possibly the fourth century, (or of the period from the fourth to the eighth centuries) there is, of course, no telling how many hands or how many minds had been concerned with it since Frontinus first wrote it.

Returning once more to the chart it is seen that little of engineering interest can be recorded in the long period of the Dark Age, and the early Middle Ages. Constantine and St. Augustine mark the practical ending of Rome's power, then follow centuries of barrenness and ignorance lightened by the brilliant but comparatively brief power of Charlemagne. Alfred the Great in England, and Hugh Capet, the first elective king of the Franks, are names which stand out as exponents of progress and the beginnings of political freedom and industrial effort.

Near the end of the eleventh century there began that singular outburst of emotional religious enthusiasm which crystallized in the Crusades. Fired by the preaching of St. Bernard, Peter the Hermit, and other enthusiasts, countless thousands entered on the holy quest of recovering the sepulchre of Christ from the hands of the infidels. Roads were bad, bridges, fords and ferries few, and travel accordingly dangerous. To build roads and bridges, to maintain ferries at suitable points on rivers, or in any other manner to help and protect pilgrims on their way, naturally became praiseworthy and pious tasks, "useful to posterity and consequently pleasing to God." A religious or semi-religious confraternity known as the "Brothers of the Bridge" (*Fratres Pontis* or *Fratres Pontifices*) came into

existence about 1177, the shepherd boy, Bénézet, afterwards canonized, being generally looked upon as the founder of the order in France. The principal source of information concerning this religious order is a small book published in Paris nearly a century ago—*Recherches Historiques sur les Congrégations Hospitalières des Frères Pontifes*, by Henri Grégoire, at one time Bishop of Blois. Brief references may be found in various encyclopedias and other general works, and rather full and extended descriptive accounts of the bridges appear in Viollet-le-Duc's *Dictionnaire Raisonée de l'Architecture Française du Moyen Age*. Definite and precise information about the brotherhood—or brotherhoods, for there were undoubtedly several organizations more or less closely bound to some central authority—is, however, hard to gather, for much of it seems to rest on legends which do not stand the test of too close analysis. But, after all, what does it matter if it appears that the shepherd lad, Bénézet, was only thirteen years old when he began the construction of the remarkable bridge at Avignon? He was divinely inspired to build it, and surely a divine inspiration more than overbalances mere youthfulness.

This bridge at Avignon, still known as the bridge of Saint Bénézet, was built in the decade from 1178 to 1188. Bénézet died before it was finished and is buried in the little chapel which surmounts one of the piers. The bridge is now in ruins, only four arch spans remaining of the original eighteen, but these show many interesting details of construction. The structure was originally over a half mile in length with a width at the roadway, including the thickness of the parapet, of about sixteen feet. The piers between the arches are exceedingly heavy in order to resist the masses of floating ice which come down the Rhone in the early spring. The current of the Rhone is rapid at this point and the river divides into two branches, one of them much wider than the other, so that the bridge itself crossed the intervening island. The arches had a clear span varying from twenty to twenty-five metres—roughly, sixty-five to eighty feet, while the piers were about thirty feet thick with

a total length up and down the river, of nearly one hundred feet.

One interesting point in regard to the arches is that the trace of the soffit is neither a parabola nor a semi-circle, but a curve which lies, roughly, midway between the two. The circular arc would have been perhaps the most natural form to use, as it is in many ways—or was at that time, at least—the easiest one to lay out either on a drawing or in the field. The parabolic form, however, is probably a better curve theoretically, and it is interesting to note that in some manner, although the theory of structures as known to-day had no existence whatever at that time, these builders were able to closely approximate the theoretically perfect curve. Each arch span is made up of four independent ribs, placed close together "in parallel," so to speak, but not tied together or bonded in any way. Each rib is a true voussoir or block-work arch, the arch-stones having a depth of about sixteen inches with closely fitting joints laid in excellent mortar. Although the individual ribs are not bonded, the heavy mass of masonry which surmounts and loads them ties the entire structure together solidly and sufficiently. The work is done with rather small stones, cut and fitted together with considerable care.

Viollet-le-Duc, from whose fascinating work on the Architecture of the Middle Ages the above details with regard to the bridge of St. Bénézet are taken, comments with gross materialism on certain practices of the builders of those days. "There are many romance constructions which show on the part of the architect a complete lack of foresight. A structure, for example, was evidently begun with a vague idea of finishing it after a certain manner, which, however, stopped half way, the constructor not knowing how to solve the problems with which he was confronted; another building could not be finished save by using means evidently not thought of in the original plan. One realizes that the early mediaeval architects built from day to day, trusting to inspiration, to chance or to circumstances, perhaps even counting on a miracle to bring their work to a satisfactory

conclusion. The legends connected with some great buildings (and the buildings themselves are there to show us the difficulties of the architects) are full of dreams during which these architects saw some saint taking the trouble to show them how they should build their vaults or support their columns; something which did not always keep the structures from falling down after they were finished, for faith alone does not suffice for building."

A few miles up the river from Avignon is the bridge of Saint Esprit, said by Viollet-le-Duc to be the last important work of the Brothers of the Bridge. This comprises twenty-two arches, each a full centered span, the other details being not unlike those of the Avignon bridge. Thirty years were occupied in building the bridge of Saint Esprit, and after its completion the brotherhood seems to have fallen into a slow decadence which léd at last, about the middle of the fourteenth century, to its dissolution. The final breaking-up came largely as a result of the corruption which so often follows increase of power and wealth, for the order had fallen away from the strict rules of poverty and humility which characterized the earlier brothers, and which had such striking exemplification in the contemporary followers of Saint Francis of Assisi.

The Brothers of the Bridge came into being to meet a specific need of the time. Perhaps it is natural enough that, after the need had passed away, the brotherhood should die a natural death. It is a pity, however, that the history of its last years should be marred by cupidity and ill-used power. In order to give greater emphasis to the good they did, it is worth while to quote here the words (in translation) in which Bishop Grégoire sums up the high aims and unselfish activities of the Brotherhood at its best: "To give lodging to travelers, to care for them if they were ill, to help them across rivers, to go with them and lend a strong and brave hand against the attacks of the brigand troops often found in those lawless times, to construct bridges, ferries, dams, roads, such were the constant labors of the Brothers of the Bridge who in that way helped the development of

some branches of industry and were in many ways the restorers of architecture and commerce."

Once more we must skip rapidly along the time-chart, this time, however, over centuries full of the charm of great names of artists, reformers, builders, and writers. The period of the Renaissance, and the later period up to the French Revolution and the beginnings of our own national existence, are full of the more intense and vital interest of comparatively recent history. There is, however, only one other book, a record of a great achievement, which will be commended this afternoon to the attention of the student of engineering history. This is Robert Stevenson's story of the building of the Bell Rock lighthouse, as told by his grandson, Robert Louis Stevenson, in his essay on "A Family of Engineers." It is hard to find its equal as a tale of remarkable accomplishment in spite of almost insurmountable difficulties. The lighthouse was built on the dangerous Inchcape Rock—made famous in Southey's poem—a ragged ledge off the east coast of Scotland some twelve miles from the mainland. The rock is bare only at certain stages of the tide, so that the difficulties of carrying on building operations, which had to be suspended entirely during the winter months, were unusually great. The record of the work, which extended over five consecutive summer seasons, is in the form of a diary kept by the elder Stevenson and edited by his grandson. The engineer Stevenson was a careful and painstaking recorder of events and processes, as well as an energetic and able designer and builder, and he sets forth both successes and failures in a frank and exact manner.

One discussion in Stevenson's book, which he treats at some length, concerns the matter of Sunday work, and makes rather interesting reading in this day when so little attention is paid to that question. In the earlier stages of the Bell Rock project, especially during the preparation of the surface of the ledge to receive the artificial foundation, it was possible to work but a short time—sometimes hardly more than an hour or two—twice each day. These working

periods were, of course, entirely dependent upon the tide, and the question of working on Sunday, in order to make the most of the limited opportunities, was bound to be raised. It meant a severe struggle with the stern Scotch conscience. The pros and cons were argued—or better, perhaps, deliberated—in sessions at which the entire little group of workmen were present, and every phase of the question was critically examined. The idea which finally prevailed was that the work on which they were engaged was a "work of humanity and necessity," and that there could be, therefore, no offense in Sunday labor. It was, however, left to each individual workman to do as he thought right, and all but two of the number agreed to work Sunday whenever the tide permitted.

It is possibly needless to suggest in conclusion the idea which is uppermost in these activities of three such widely separated periods. Differing greatly as they do in the nature of their work and their manner of doing it, the dominant note is still the spirit of service, the recognition of a public need and a striving to fill it. The sturdy Scotch colleagues of Stevenson, who subordinated their strict ideas of Sabbath observance to a dangerous work of necessity, the Brothers of the Middle Ages who expressed their religious enthusiasm in lasting creations of stone and mortar for the good of their fellowmen, and the faithful and energetic water commissioner of Rome, whose chief desire was to keep the city well supplied—all were inspired by the same ideal of useful, creative work. It is the ideal that dominates the work of the engineering profession to-day, and must so continue if the profession is to live.

The Brothers of the Bridge sometimes marked their bridges with the following couplet expressive of their belief in creative labor for the good of others. Although coming from an age when religious feeling was a simpler and more universal companion of daily life than it is to-day, it has a lesson for all time, and furthermore throws an interesting side-light on the character of those early workers. It is a rare expression of a simple and unselfish creed growing

out of inspired work. Who the writer was we are not told, but his hand must have been that of a true master and he himself a loyal "Brother of the Bridge"—

> "Straverunt alii nobis, nos posteritati,
> Omnibus ut Christus stravit ad astra viam."*

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*Those who have gone before us
Have paved the way.
So must we build new roads
For those who come;
Even as Christ himself has paved for all
The Way to Life.

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